

EVALUATION OF THERMAL PROTECTION TILE TRANSMISSIBILITY FOR GROUND VIBRATION TEST

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NOMENCLATURE

CHEXA	Solid element used in NASTRAN
CQUAD	Shell element used in NASTRAN
FRF	Frequency response function
GVT	Ground vibration test
RBAR	Rigid element
TPS	Thermal protection system
pcf	lb/ft ³

ABSTRACT

Transmissibility analyses and tests were conducted on a composite panel with thermal protection system foams to evaluate the quality of the measured frequency response functions. Both the analysis and the test results indicate that the vehicle dynamic responses are fully transmitted to the accelerometers mounted on the thermal protection system in the normal direction below a certain frequency. In addition, the in-plane motions of the accelerometer mounted on the top surface of the thermal protection system behave more actively than those on the composite panel due to the geometric offset of the accelerometer from the panel in the test set-up. The transmissibility tests and analyses show that the frequency response functions measured from the accelerometers mounted on the TPS will provide accurate vehicle responses below 120 Hz for frequency and mode shape identification. By confirming that accurate dynamic responses below a given frequency can be obtained, this study increases the confidence needed for conducting the modal testing, model correlation, and model updating for a vehicle installed with TPS.

1 INTRODUCTION

Accurate prediction of the dynamic loads or the controllability of an aircraft is normally based on a test-verified analytical model. This requires that the dynamic characteristics such as the frequencies and mode shapes be measured from a modal survey or ground vibration test (GVT) [1-4]. However, for a space vehicle with thermal protection tiles (TPS) attached to its airframe the accelerometers inevitably need to be mounted on the thermal tiles during the test. In order to determine whether the measured frequency response functions (FRF) represent the true dynamic behavior of the structure, the transmissibility of the thermal tiles has to be evaluated. Limited study has been conducted to evaluate the effects of the TPS on the quality of the measured FRFs. In order to support modal test planning for an on-going program, testing of representative TPS foam samples bounded to

representative composite panels was proposed and carried out. Two TPS foam blocks with a four inch thickness and one TPS foam block with a three inch thickness having various densities were bonded on a 20" x 20" composite panel for the transmissibility study. Various densities (pounds per cubic foot, pcf) of TPS foam specimens available from the vendor were used for the tests. The fabricated composite panel was used to simulate a typical fuselage panel. FRFs measured directly from the composite panel were compared to FRFs measured on the TPS blocks to evaluate the attenuation of the dynamic responses.

Finite element analyses were also conducted to analytically evaluate the effects on the frequency response functions by mounting the accelerometers on the TPS foam blocks instead of on the hard surface which would be inaccessible during a GVT of the overall vehicle. The models developed for these analyses were constructed to the same test configurations employed in the TPS transmissibility tests. The objective of the analysis was to identify the trend of the predicted frequency response functions of the TPS foams and the composite panel in order to support the GVT. The analysis results were also used to assist the test planning. In addition to providing guidance for GVT planning, the effects on the frequency response functions due to the geometric offset of the accelerometer locations were also investigated.

2 ANALYTICAL PREDICTIONS

In order to analytically evaluate the impacts of mounting the accelerometers on the TPS foams instead of on the hard surface of a test article for measuring the FRFs finite element analyses were conducted. Three types of TPS foams with different geometry and weight density were evaluated. Two foams have a four inch thickness and the third has a thickness of three inches. All three TPS foams were bounded on a 20" x 20" composite panel using the same adhesive and process used on the flight vehicle. The objective of the analysis was to assess how the TPS would affect the transmissibility of the frequency response functions for the GVT.

2.1 Analysis Configurations

Two analysis configurations, described in Table 1, were performed to study the transmissibility of the TPS foams and the frequency responses due to the geometric offset of the accelerometer locations. The finite element model shown in Figure 1 consists of three 6" x 12" TPS foam blocks that were modeled as CHEXA solid elements and one 20" x 20" composite panel which was modeled as CQUAD plane stress shell elements. The panel is constrained along one edge to represent a clamped boundary condition. The Young's modulus and the Poisson's Ratio of the TPS foam used in this study were provided by the vendor. The locations where the dynamic responses were recovered and compared are listed in Table 2. "White noise" excitation with unit amplitude from 0.0 Hz to 200.0 Hz was applied to the load application point shown in Figure 1 and a frequency resolution of 0.5 Hz was used. Note that redundant rigid elements representing the offset locations from the composite panel were also modeled as RBARs for evaluating the effects of the flexibility of the TPS foams on the frequency responses.

Table 1. Finite Element Analysis Configurations

Analysis	Composite panel	TPS foams
Frequency Response Analysis	Carbon panel	One 6" x 12" x 4" One 6" x 12" x 4" One 6" x 12" x 3"
Base Drive Analysis	Carbon panel	One 6" x 12" x 4" One 6" x 12" x 4" One 6" x 12" x 3"

Table 2. Dynamic Response Recovery Locations

Location	Descriptions	FE Elements
33	On composite panel	CQUAD4
331	On TPS Foam 1	CHEXA
332	Offset from 33 at the same location as 331	RBAR
63	On composite panel	CQUAD4
631	On TPS Foam 2	CHEXA
632	Offset from 63 at the same location as 631	RBAR
93	On composite panel	CQUAD4
931	On TPS Foam 3	CHEXA
932	Offset from 93 at the same location as 931	RBAR

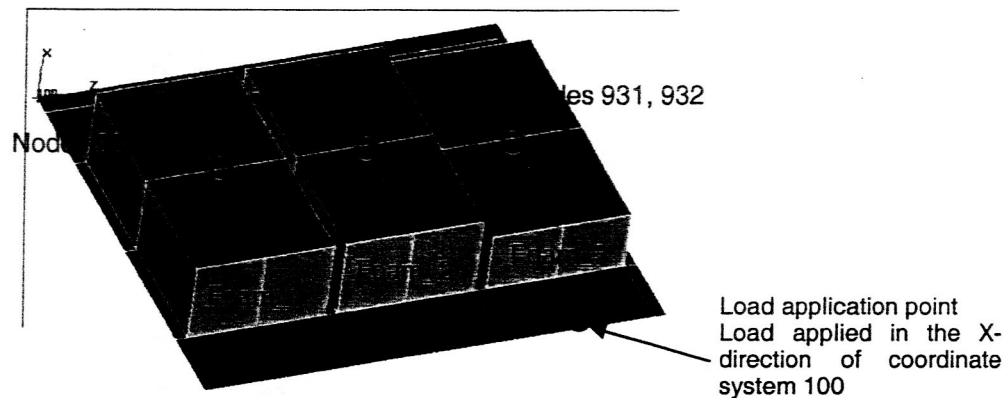


Figure 1. Finite Element Model for TPS Transmissibility Analysis

2.2 FRF Analysis Results

The FRF at three grid locations (33, 63, and 93) on the composite panel and three grid locations (331, 631, and 931) on the TPS foam blocks due to "white noise" excitations were computed. Grid pairs 33 and 331, 63 and 631, and 93 and 931 are used to compare the frequency responses at the same position with one located on the panel and the other located directly above it on the top surface of the TPS foam blocks. The comparison of the predicted FRFs for each TPS foam are shown in Figures 2 through 4, respectively.

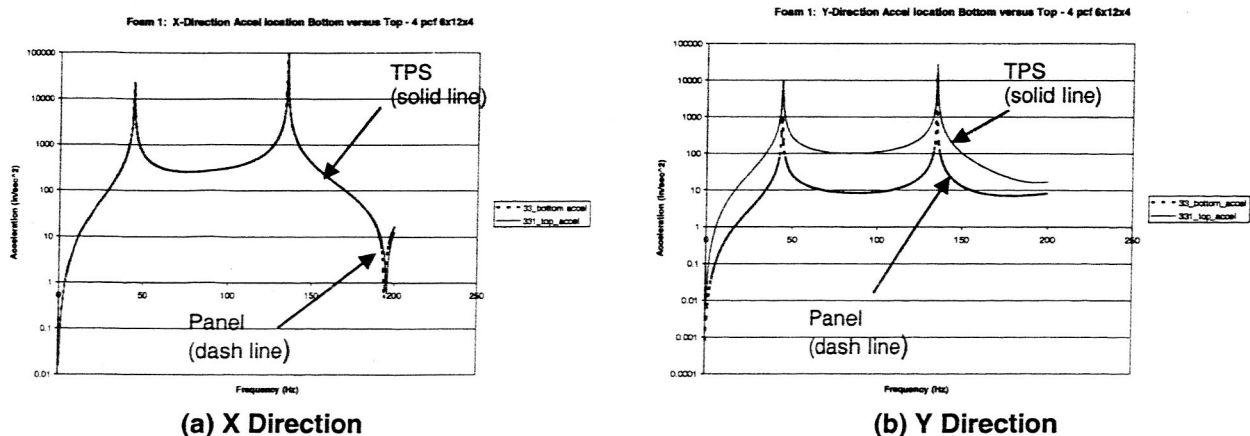
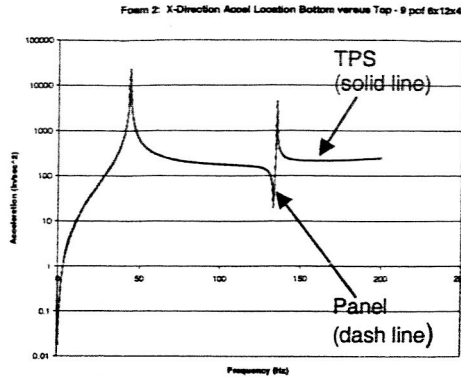
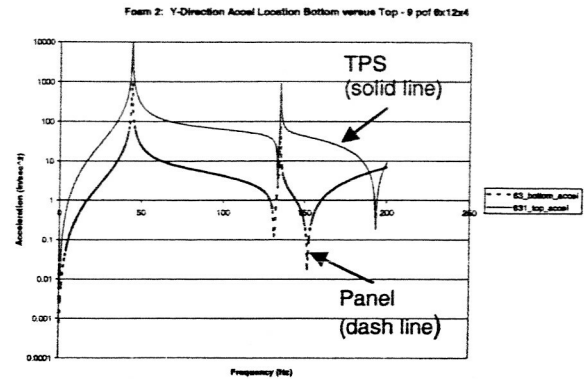


Figure 2. Comparison of Panel and TPS FRF for Locations 33 and 331

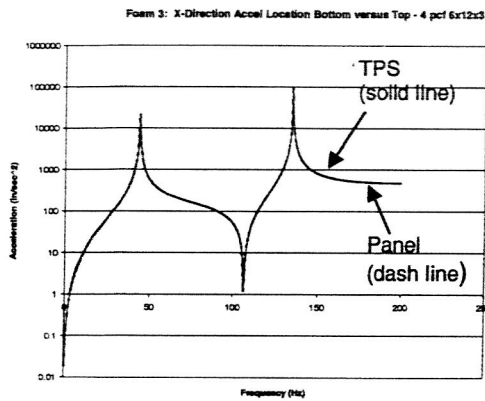


(a) X Direction

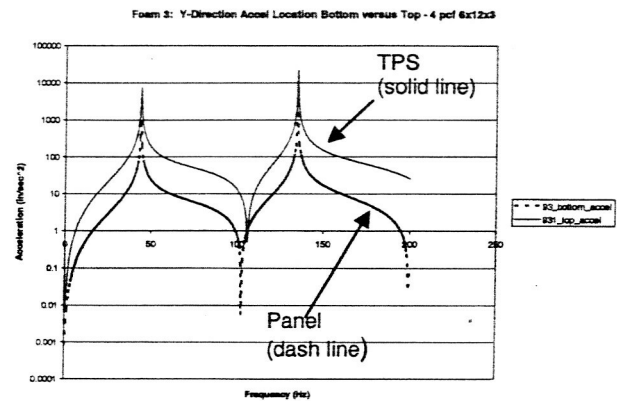


(b) Y Direction

Figure 3. Comparison of Panel and TPS FRF for Locations 63 and 631



(a) X Direction



(b) Y Direction

Figure 4. Comparison of Panel and TPS FRF for Locations 93 and 931

2.3 Base Drive Analysis Results

The results from the FRF analysis show that the frequency responses at the panel surface and at the TPS foam are similar in the direction perpendicular to the panel. However, in the directions parallel to the panel surface the frequency response at the TPS foam exhibits a constant response offset from the response at the panel surface. A base drive analysis was conducted to study the "offset" phenomenon observed from the FRF analysis. All the grid points of the composite panel were attached to a large mass weighing 1.0×10^{10} lb as shown in Figure 5. Then a force of 1.0×10^6 lb was applied to this large mass in the lateral direction to "drive" the composite panel to move laterally at 0.0001g. The frequency responses at the panel and at the top surface of the TPS in the lateral directions were determined and compared in Figures 6 and 7. It is observed that the response at the TPS is identical to the response at the panel for both lateral directions. This verifies that the response "offset" shown in the TPS transmissibility analysis results is indeed due to the geometric offset of the TPS accelerometer locations. The offset of the TPS top surface is also seen from the mode shape plots shown in Figure 8.

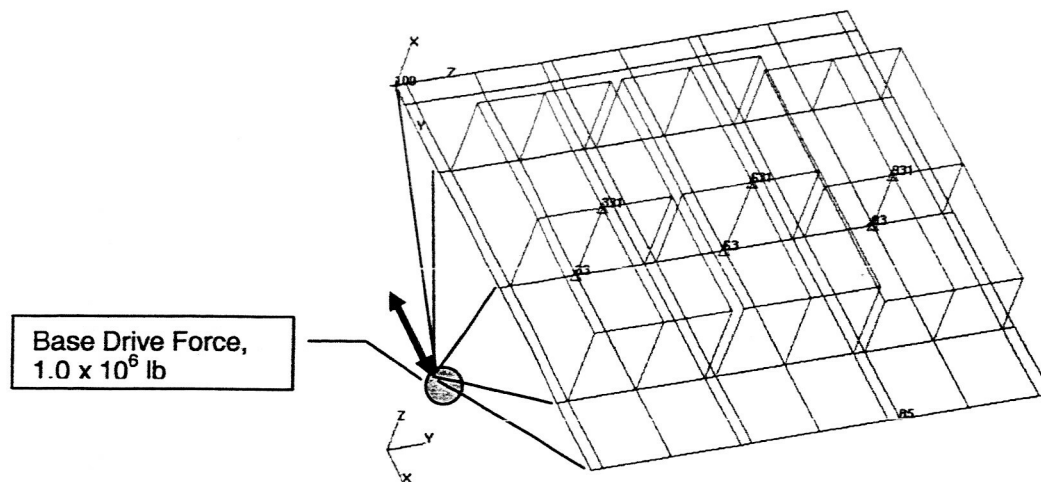
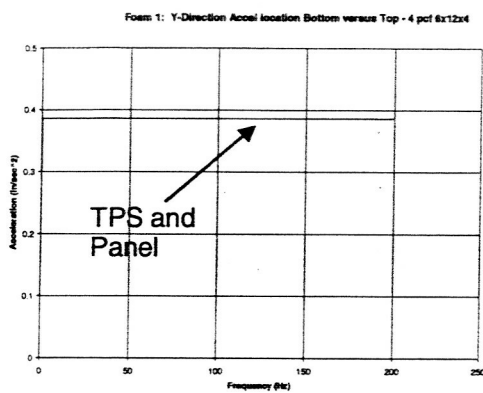
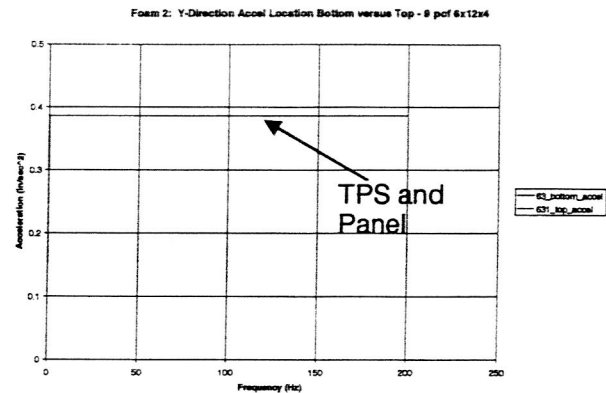


Figure 5. FEM for Base Drive Analysis in Lateral Directions

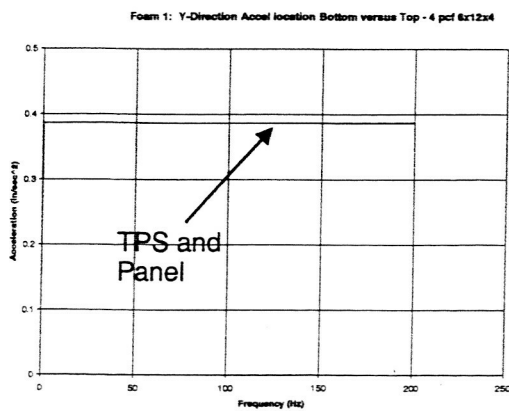


(a) Locations 33 and 331

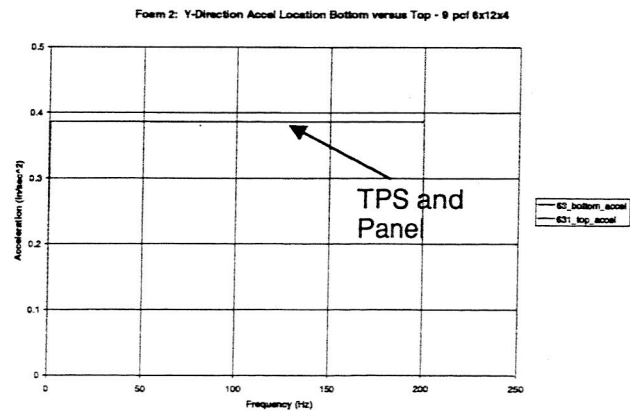


(b) Locations 63 and 631

Figure 6. Comparison of Panel and TPS FRF - Y Direction

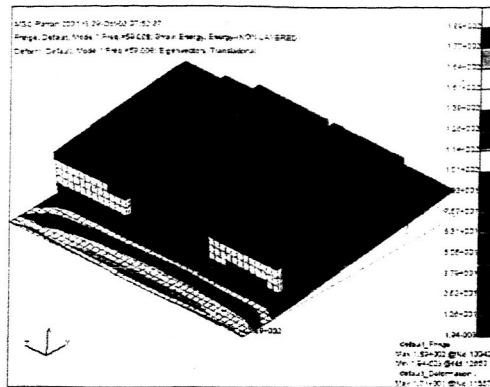


(a) Locations 33 and 331

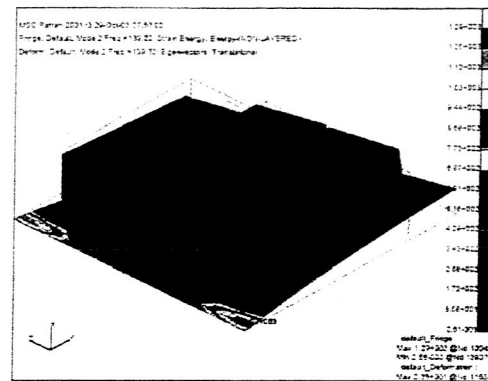


(b) Locations 63 and 631

Figure 7. Comparison of Panel and TPS FRF - Z Direction



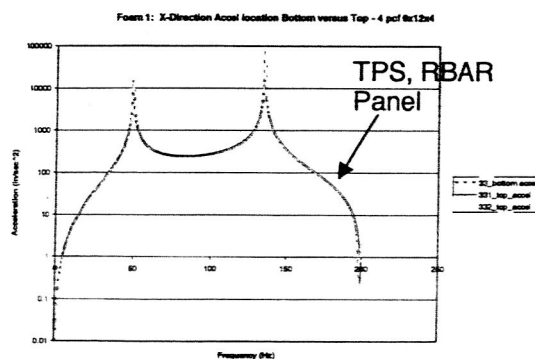
(a) Bending Modes



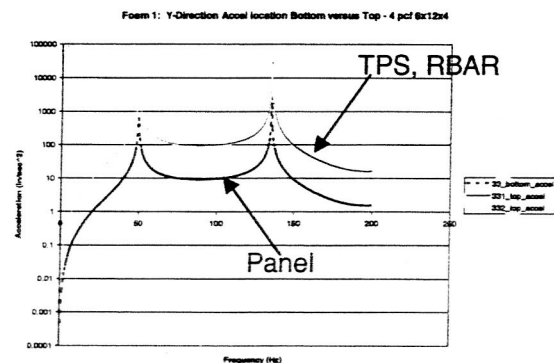
(b) Twisting Modes

Figure 8. Mode Shape plots of Panel/TPS Finite Element Model

An FRF analysis was repeated to evaluate the frequency responses at the top of the TPS by using elastic and rigid elements. The grid pairs 331 and 332, 631 and 632, and 931 and 932 are located at the same locations and were used to evaluate the effects of the geometric offset of the accelerometer locations. Grids 331, 631, and 931 were connected to the panel using the elastic properties of the TPS while grids 332, 632, and 932 were rigidly connected to the panel. The transfer functions for these three locations are shown in Figures 9 through 11. The plots show that the lateral responses at the rigidly connected locations are identical to those locations elastically connected to the panel in the frequency range of interest. This clearly verifies the geometric "offset" of the accelerometer on the TPS block from the panel produces a shift of the frequency response function in the lateral directions.

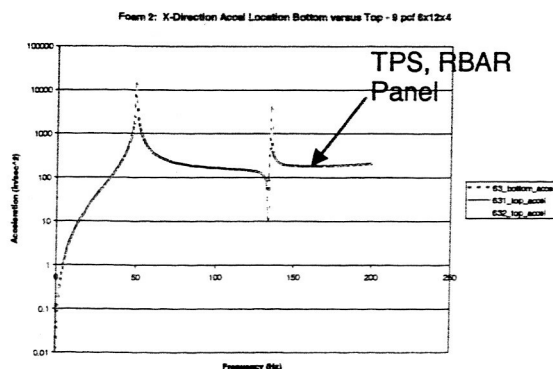


(a) X Direction

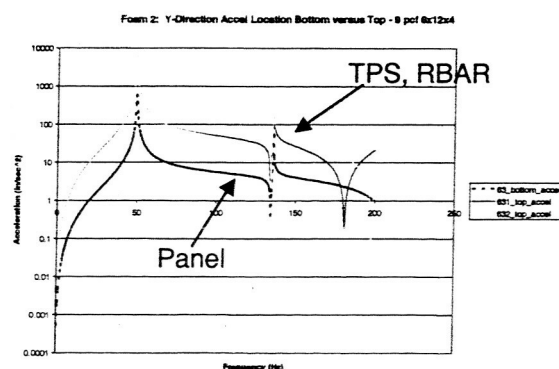


(b) Y Direction

Figure 9. Comparison of FRF for Rigidly and Elastically connected Locations - 331 and 332



(a) X Direction



(b) Y Direction

Figure 10. Comparison of FRF for Rigidly and Elastically connected Locations - 631 and 632

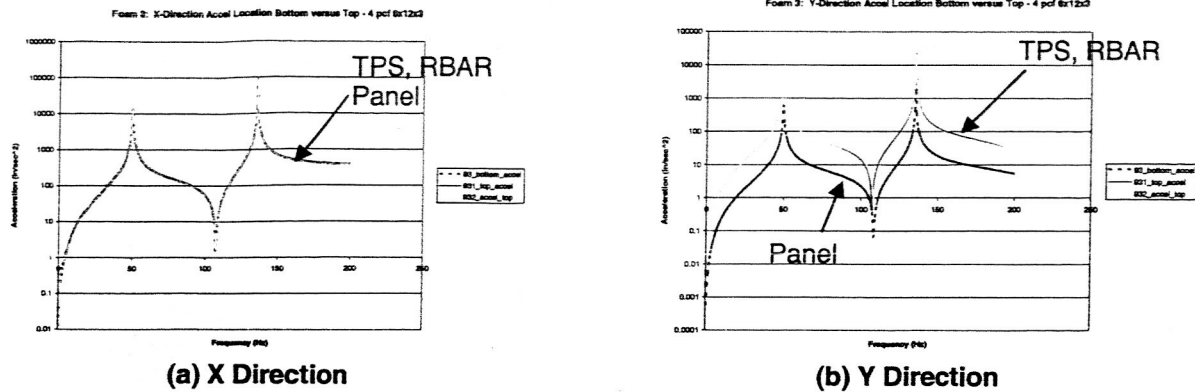


Figure 11. Comparison of FRF for Rigidly and Elastically connected Locations - 931 and 932

3 Transmissibility Tests

Modal tests were conducted on the composite panel/TPS test article representing the analysis configuration described in Section 2.1. A tri-axial accelerometer was mounted on the top surface of each TPS foam block. Three tri-axial accelerometers were also mounted at the corresponding locations on the other side of the panel. The frequency response functions measured from the composite panel and the TPS surface were compared to evaluate the attenuation of the dynamic responses.

3.1 Test Configurations

The test article consisted of three 6" x 12" TPS foams mounted on a 20" x 20" composite panel. The panel was clamped on one side. Six tri-axial accelerometers were mounted on the composite panel and the TPS blocks as shown in Figure 12.

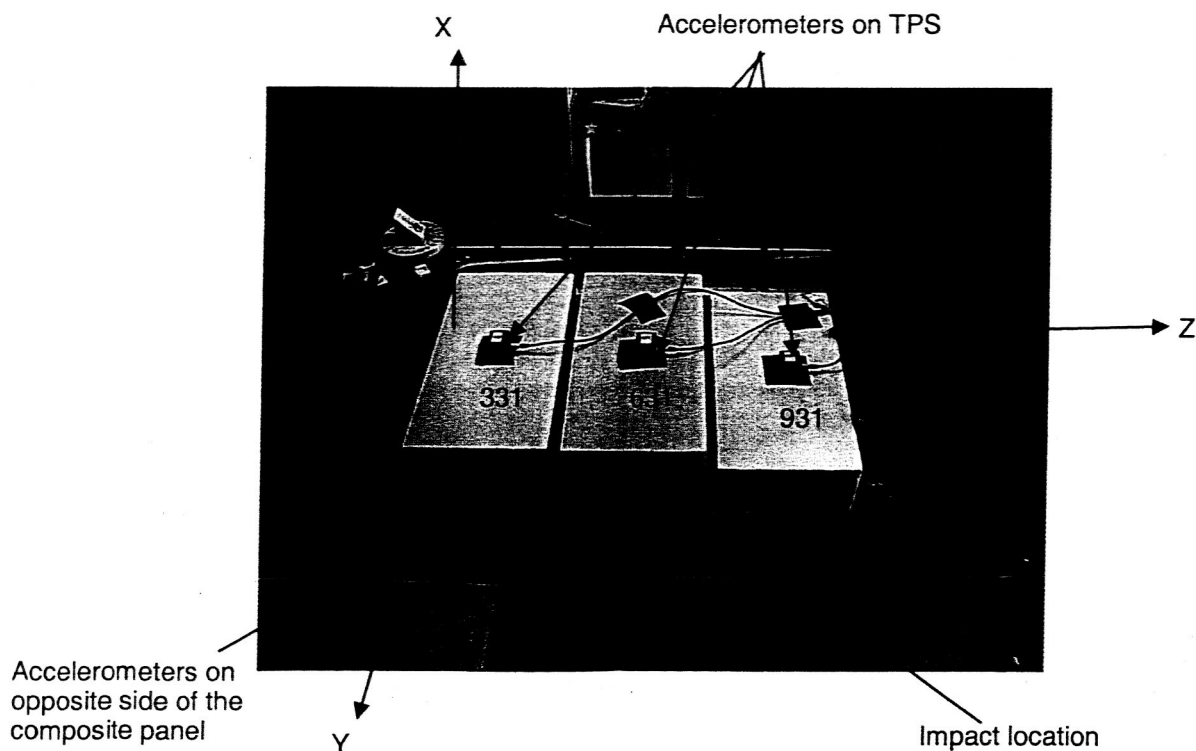


Figure 12. Test Set-Up for the Transmissibility Test

3.2 Test Results

The frequency responses in the X, Y, and Z directions of the six tri-axial accelerometers mounted on the test article, as shown in Figure 12, were measured due to the modal impact hammer excitations. Accelerometer pairs 33 and 331, 63 and 631, and 93 and 931 were used to compare the responses at corresponding positions on the TPS foam blocks and the panel. Comparisons of the measured FRFs are shown in Figures 13 through 15, respectively. Note that the primary response that would be measured in the GVT is in the X-direction (normal to the composite panel surface). The plots show that the FRF measured on the TPS foam blocks and on the panel are very compatible below 120 Hz in the direction normal to the panel. The FRF measured for the accelerometers on the TPS surface show larger lateral motions than the FRF on the panel. This is because the TPS accelerometers were mounted further away from the constrained plane and the TPS foam blocks were not continuous in the test setup. This larger lateral motion for the TPS accelerometers observed in the TPS transmissibility tests were also predicted in the frequency response analyses due to the geometric offset of the accelerometer locations.

4 CONCLUSIONS

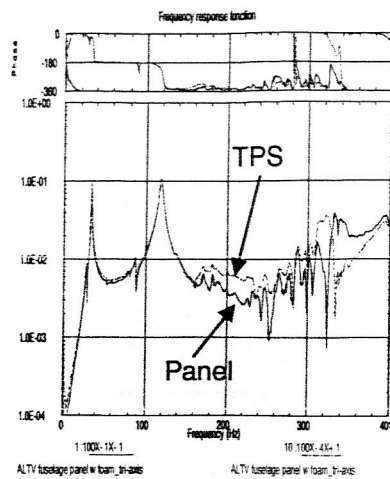
The results of the frequency response analyses show that the analytical model predicted a similar frequency response signature as the TPS transmissibility tests. In addition, the base drive analyses validated the observation that the response offsets in the lateral directions are due to the "geometric offset" of the TPS accelerometer with respect to the composite panel. The test results indicate that the vehicle dynamic responses are fully transmitted to the accelerometers mounted on the TPS in the normal direction below 120 Hz. However, the TPS in-plane motions are more active than those on the composite panel due to the discontinuity of the TPS foam in the test set-up. It is expected that the in-plane motions on the TPS and the structure will be closer in a typical aircraft GVT because the TPS foams will be mounted in a continuous manner in the actual vehicle. This will minimize the local lateral motions of the TPS foams. The conclusion derived from the results of the TPS transmissibility tests and analysis indicate that the FRFs measured from the accelerometers mounted on the TPS will provide acceptable vehicle responses below 120 Hz for frequency and mode shape identification which support the necessary vehicle model correlation and model updating activities.

5 ACKNOWLEDGMENTS

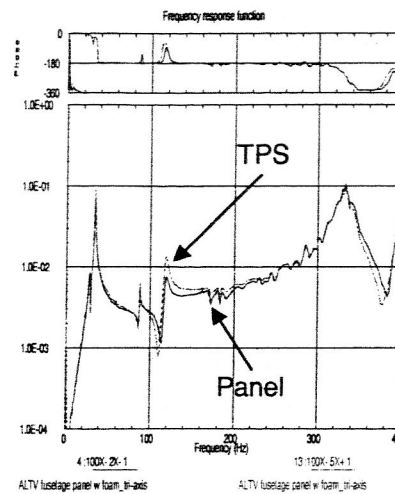
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6 REFERENCES

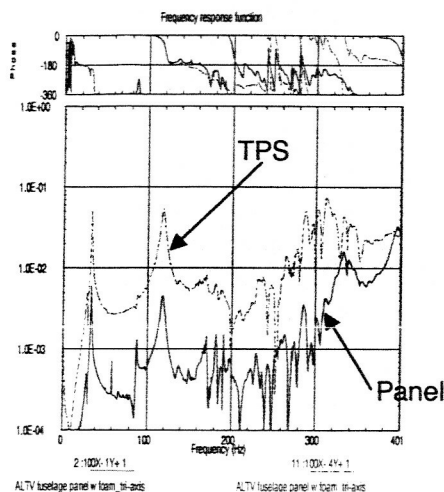
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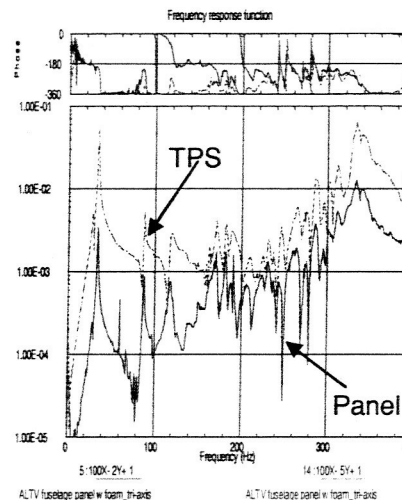
(a) X direction



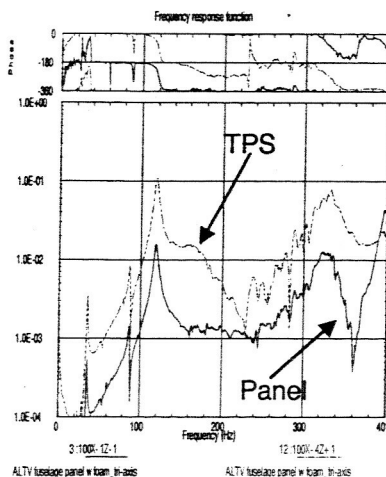
(a) X direction



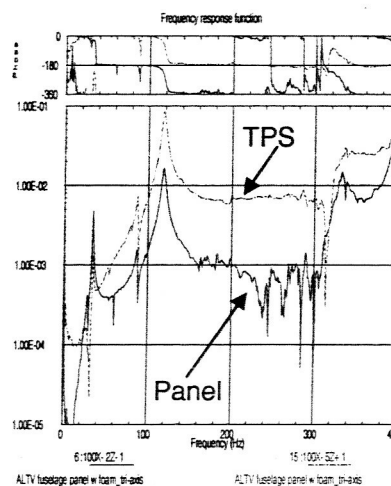
(b) Y direction



(b) Y direction



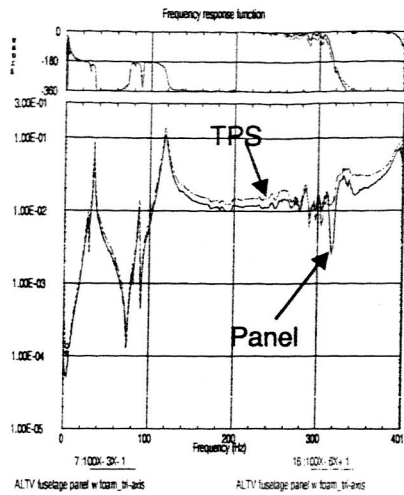
(c) Z direction



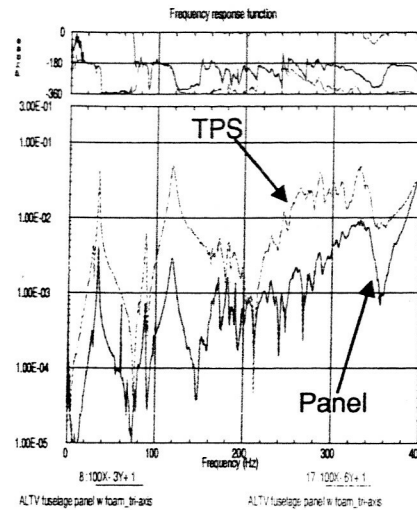
(c) Z direction

Figure 13. Panel/TPS FRF for Accel 33 and 331

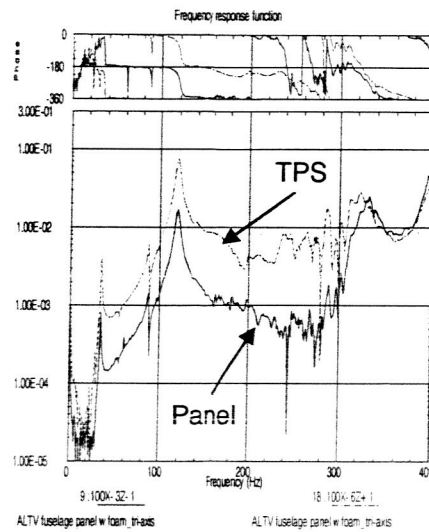
Figure 14. Panel/TPS FRF for Accel 63 and 631



(a) X direction



(b) Y direction



(c) Z direction

Figure 15. Panel/TPS FRF for Accel 93 and 931